Renewable and Sustainable Energy Reviews 21 (2013) 288–297

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Parabolic trough solar thermal power plant: Potential, and projects development in Algeria

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ARTICLE INFO

Article history:
Received 10 October 2012
Received in revised form
23 November 2012
Accepted 26 November 2012
Available online 1 February 2013

Keywords:
Parabolic trough power plant
Renewable energy program
Solar energy
CSP potential

ABSTRACT

Against the background of an increasing energy demand and growing environmental problems in Algeria due to the use of fossil fuels, renewable energy resources offer interesting opportunities for Algeria. In 2011, Algeria has developed a national program for the period 2011–2030 to promote concrete actions in the fields of renewable energies and energy efficiency.

This paper gives description and working principles of the parabolic trough power plants, besides a review of considerations on the assessments for concentrating solar power potential of Algeria. The analysis shows the competitive viability of CSP plants. Algeria has the key prerequisites to make an economical CSP power generation; including high-quality insolation and appropriate land in addition to water availability and extensive transmission and power grid.

In the end, an overview is given on the parabolic trough power plant projects development in Algeria including the first integrated solar combined cycle Hassi R'mel plant, in addition to the three further hybrid power plants that will be completed by 2018.

Contents

Abbreviations: MEM, Ministry of Energy and Mines; PTSTPP, parabolic trough solar thermal power plant; CSP, concentrating solar power; REs, renewable energies; USD, United State Dollar; SEGS, solar energy generating systems; PTC, parabolic trough collector; HTF, heat transfer fluid; SCA, solar collector assemblies; DGS, direct steam generation; DNI, direct normal insolation; DLR, German Aerospace Center; CDER, *Centre* of development of *renewable energy*; AC, alternating current; ISCCS, integrated solar combined cycle systems; NEAL, new energy Algeria company; SPP, solar power plant

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2012.11.074

1. Introduction

The global demand for energy and more specifically clean energy is growing rapidly. The environmental protection through the control of pollution and particularly the emissions of gases in the atmosphere still remains a major concern to the whole of the international community. There is no doubt that the available fossil energies would not disappear soon; nevertheless the era of abundance and cheap energy will not last long; we will have to consider alternate sources of energy, and it is clear that renewable energy is linked to environmental issues [1].

Algeria not only has one of the world's most extensive gas reserves, but also has huge renewable energy resources especially solar and wind power; the interest for the development of renewable energies was perceived very early in Algeria with the creation of the solar institute as early as 1962. Algeria has developed its own national strategy for renewable energy. The objectives are to ensure the change from hydrocarbons and a sustainable development without danger to health and without pollution for the environment.

The question of energy, climatic changes and the sustainable development has a large importance in the programs of development in Algeria. During the last decade several regulatory and institutional measures have been introduced to deal effectively with environmental concerns in development projects and with high polluting activities. The process of reform begun by Algeria has devoted special attention to the safeguarding of environment, health of the population and promotion of sustainable development; as a result, measures have been adapted to strengthen the legal and institutional frameworks in order to give the country a relevant environmental policy and appropriate mechanisms for its implementation.

Fortunately, Algeria has enormous potential of renewable sources of energy, especially of solar energy, in which it is the top source in the Mediterranean basin; more than 2,000,000 km^2 receives yearly a sunshine exposure equivalent to 2500 kWh/m^2 and the mean yearly sunshine duration varies from a low value of 2650 h on the coastal line to 3500 h in the south [2].

The development of solar energy plants is supported by the Ministry of Energy and Mines (MEM) and realized mainly by Sonelgaz and other private installer companies. Solar energy is regarded as an important line of research within the structure of the department of renewable energies of Sonelgaz [3].

Parabolic trough solar thermal power plant (PTSTPP) is one of the attractive technologies to produce electricity from thermal solar energy that use mirrors to focus sunlight onto a receiver that captures the sun's energy and converts it into heat that can run a standard turbine generator or engine. PTSTPP systems range from remote power systems as small as a few kilowatts (kW) up to grid-connected power plants of 100s of megawatts (MW). The process of energy conversion by PTSTPP consists of two main parts:

- The concentration of solar energy and converting it into usable thermal energy.
- The conversion of heat into electricity, which is realized by a conventional steam turbine.

This paper goes on to give a review on the assessment of concentrating solar power (CSP) potential, and PTSTPP projects development in Algeria.

2. Renewable energy program related to CSP technology

The question of energy, climatic changes and the sustainable development has a large importance in the Algerian programs of development. In 2011 the Algerian MEM launched the renewable energies (REs) and energy efficiency program, with a total cost of 120 billion USD [3]; this program leans on a strategy focused on developing and expanding the use of inexhaustible resources, such as solar energy in order to diversify energy sources and prepares Algeria for tomorrow.

The strategic choice is motivated by the huge potential in solar energy; this energy is the major focus of the program of which solar power and photovoltaic systems constitute an essential part. Solar should achieve more than 37% of national electricity production by 2030. Despite its relatively low potential, wind energy is not excluded from the program as it constitutes the second axis of development with a share in electricity production expected to reach about 3% in 2030 [3].

Algeria is indeed aiming to be a major actor in the production of electricity from CSP, which will be drivers of sustainable economic development to promote a new model of growth.

The REs program for concentrating solar thermal power technology development is based on three stages [3]:

- During 2011–2013: 300 MW of CSP.
- From 2016 to 2020: 1200 MW of CSP will be installed.
- From 2021 to 2030: a capacity of about 600 MW per year will be installed.

In addition to the hybrid solar–gas technology with a total capacity of 175 MW by 2014.

This part of the program of REs is a part of Algeria's strategy, which is aimed at developing a genuine solar industry along with

a training and capitalization program that will ultimately enable the use of local engineering and establish efficient know-how, including the fields of engineering and project management. The aim of the REs program for CSP is to meet domestic needs in electricity, and will generate several thousand of direct and indirect jobs.

3. Review of parabolic trough solar thermal power plants technology

A parabolic trough solar thermal power plant (PTSTPP) is considered as one of the most mature, successful, and proven solar technologies for electricity generation [4,5]. The first oil crisis in the early 1970s marked the beginning of modern development of CSP plants worldwide. R&D activities were started on several continents, and experimental and pilot solar power plants were erected and operated, but it was in the United States where PTSTPP technology reached its maximum maturity, with the solar energy generating systems (SEGS) developed by Luz International Ltd., at 354 MW, being the largest SEGS facility in the world. It consists of nine solar power plants in California's Mojave Desert, where insolation is among the best available in the United States. The SEGS I–II plants are located at Daggett, the SEGS III–VII ones are installed at Kramer junction, and the SEGS VIII–IX are placed at Harper Lake [5].

3.1. Components of PTSTPP

The analysis of the components is based on state of the art technology that consists of a parabolic trough collector (PTC) filled using thermal oil as heat transfer fluid (HTF) and the power block. Optionally, thermal energy storage may be used as shown in Fig. 1.

3.1.1. Solar field

A solar field consists of hundreds of solar collector assemblies (SCA), which are independently tracking assemblies of PTCs. Each SCA has the following components: metallic support structure, mirrors, solar receiver, and collector balance of the system (Fig. 2).

In order to reach the operational conditions, the solar collector assemblies are arranged in a series configuration normally known as a loop; the length and the shape of the loop depends on the parabolic trough collector (PTC) performance, but it usually has a U shape to minimize the pressure drop through the pipe header. Usually the PTCs are oriented in north–south direction tracking the sun from east to west, but this also depends on the land constraints [7].

3.1.2. Thermal storage

Thermal energy storage is practically and economically feasible already today, even in large-scale applications. Solar thermal power plants can be equipped with thermal energy storage with a full-load storage capacity in the range of several hours. It is usually seen that the storage is filled during the day, and emptied again after sunset; so that electricity is still produced even after sunset, this allows for plant operation in concordance with load requirements from the grid, because in many countries there is an electricity demand peak after sunset. During such demand peaks, electricity prices are usually far higher than base-load prices, creating a very important added value of CSP and storage [6].

Various thermal storage technologies are in principle feasible for solar thermal power plants, based on different physical mechanisms (such as sensible heat storage, latent heat storage, and chemical energy storage), and by applying different types of storage materials (such as molten salt, oil, sand, and concrete). The storage material needs to be cheap, because large quantities are required.

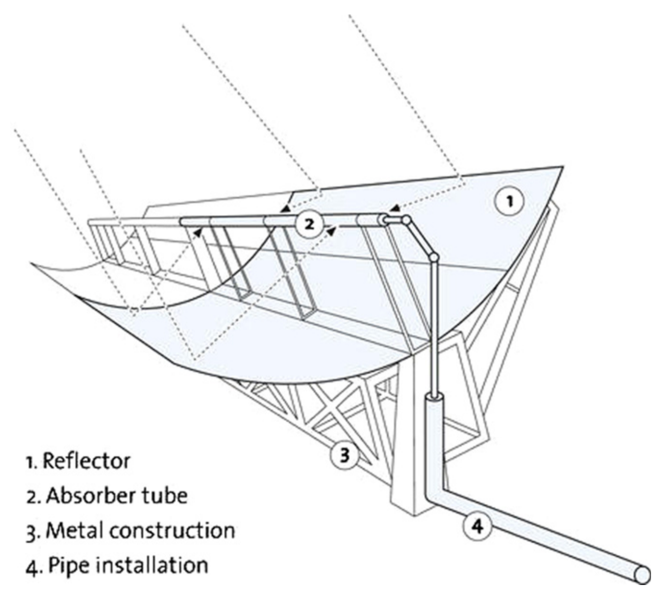

Fig. 2. Parts of a solar collector assembly (SCA) [7].

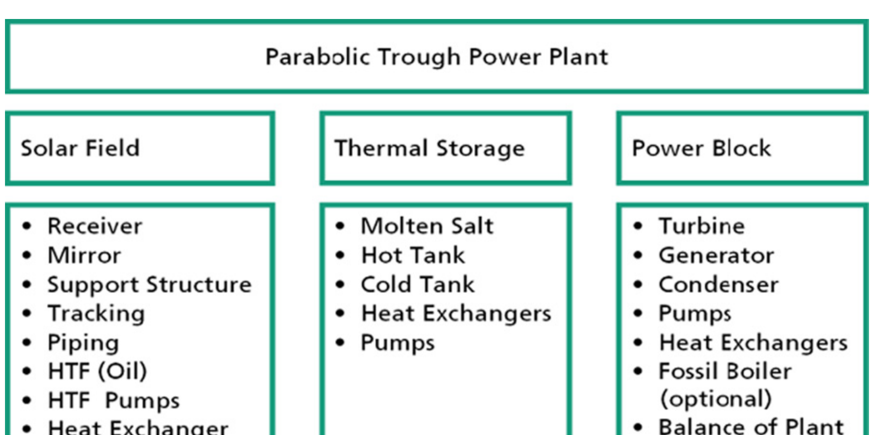

Fig. 1. Components of a parabolic trough power plant are the solar field and the power block. Optionally, thermal storage may be integrated [6].

3.1.3. Power block

Behind the solar field is the workhorse of a CSP plant, the power block. Regardless of the solar field technology, the power block needs to provide reliable, efficient power. The power block commonly used in concentrating solar thermal power plants is a Re-generative Rankine Cycle for electrical power generation; it includes mainly the steam heat exchanger where steam is produced and the steam-turbine generator that produces electricity [6].

3.2. PTSTPP configuration

Parabolic trough power systems vary in configurations and operating systems; each one can be installed in solar mode only where only heat from the solar field is used to operate the thermal cycle. However, these systems require a thermal storage facility to ensure operation stability. Hybrid systems use different approaches, where the fossil fuel boiler is utilized (commonly natural gas fired) or any other renewable source to supply the required energy for the thermal power plant to be used. Boilers are connected in parallel to the solar field to heat up the feed water or to superheat the generated steam in the thermal cycle [8].

3.2.1. Solar only mode

In this configuration and operation system the only energy resource to run the thermal plant is the solar field. There is no backup or assistance from fossil fuels boilers. However, a thermal storage system is needed in this regime (Fig. 3). The average solar-operating hours are 10–12 h during the summer [8]; for the remaining time the plant is operated by energy from thermal storage. In solar only mode with storage the solar field starts running from sunrise to supply heat to the Rankin cycle. For about 2–3 h of solar radiation peak, the solar field is operated to supply some energy to storage system in addition to its primary task of running the steam turbine, and when solar energy is not sufficient to run the Rankin cycle, the storage system starts to supply some energy to the thermal cycle. After sunset the plant runs completely on the storage system [8].

3.2.2. PTSTPP with direct steam generation (DSG)

The used HTF in most of the existing parabolic trough solar fields are synthetic oils; these oils are used as a medium to supply the generated energy from the solar field to the thermal power plant. Heat exchangers are used to supply this energy to water in the thermal cycle that is usually a Rankin cycle. The concept of DSG is to use water as an HTF in the PTC field, so that the solar field preheats, evaporates and superheats the water feed. Accordingly, steam can be expanded at a steam turbine directly. The benefits of this operation strategy are cutting capital and operation costs. Using water as an HTF results in eliminating the use of expensive synthetic oils and eliminating the heat exchanger from the power plant. Furthermore, the thermal efficiency of the thermal cycle is increased [8].

3.2.3. Hybrid system

Since the solar radiation is only available for part of each day, energy storage, as discussed above, represents one means of providing power around the clock. An alternative way of exploiting solar energy when continuous power is needed is to combine a solar thermal power plant with a fossil fuel or other source of energy power plant.

The hybrid system of solar power generation concept uses a backup fossil fuel boiler that is used in parallel to the solar field to guarantee reliable operation at night-time or when no solar radiation is available. Many configurations have been introduced as hybrid systems, and one of the fossil fuel boilers or more are used to supply the required energy for the thermal cycle; these boilers can be used to superheat the steam in the thermal cycle; moreover in the hybrid systems one solar field or more are allocated in different positions either to heat the feed water or superheat the steam [6,8].

4. Assessment of the potential of concentrating solar power use in Algeria

Evaluated siting parameters for centralized concentrating solar power plants are required before locating a real plant. The potential for CSP implementation in Algeria depends on identifying and analyzing these technical and economical parameters and issues which are listed in Table 1 and studied, in addition to other parameters.

4.1. Solar resource

Due to the nature of CSP technology, only the direct normal insolation (DNI) can be used which limits the high-quality CSP sites to areas with low levels of atmospheric moisture and particulates, little or no cloud cover, and high levels of DNI around the year, deserts thus being the most typical for these conditions [10]. Further, the required solar field size for CSP is directly proportional to the level of DNI, with the solar field representing about 50% of total project cost; the DNI level will have the greatest impact on

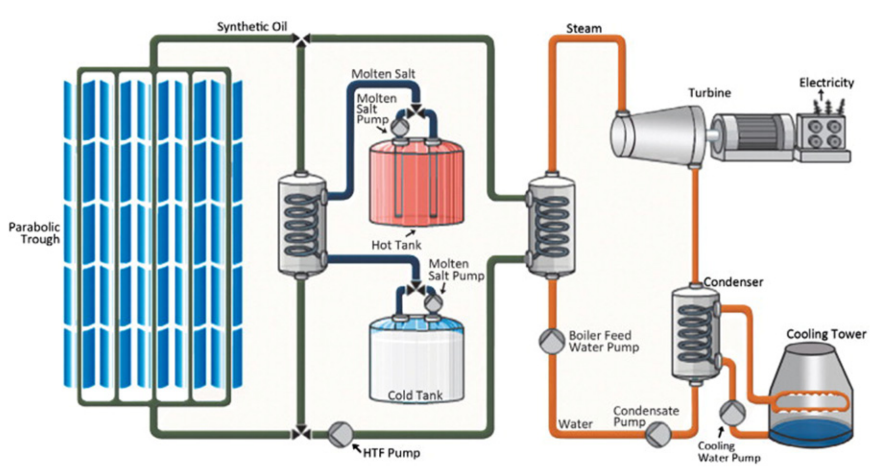

Fig. 3. Sketch of a two tank molten salt solar thermal energy storage embedded into a CSP power plant [6].

overall CSP system cost since the CSP systems require high DNI for cost-effective operation. Sites with excellent solar radiation can offer more attractive levelized electricity prices, and this single factor normally has the most significant impact on solar system costs [10]. It is generally assumed that concentrating solar power systems are economic only for locations with DNI above (1800 kWh/m^2/year) (circa 5 kWh/m^2/day) [10,11].

The geographic location of Algeria, in the Sun Belt region, and the climatic conditions such as the abundant sunshine throughout the year, low humidity and precipitation, and plenty of unused flat land close to road networks and transmission grids, have several advantages for the extensive use of the solar energy as enormous potential for power generation compared to global energy demands.

According to a study of the German Aerospace Agency (DLR) based on satellite imaging (Fig. 4), Algeria, with 1,787,000 km^2, has the largest long term land potential for the concentrating solar power in the Mediterranean basin. In addition, as shown in Table 2 [12], the value of solar radiation falls between 4.66 kWh/m^2 and 7.26 kWh/m^2; this corresponds to 1700 kWh/m^2/year in the north and 2650 kWh/m^2/year in the south. The insulation time over the quasi-totality of the national territory exceeds 3000 h annually and may reach 3500 h in Sahara. With this huge quantity of sunshine per year, Algeria is one of the countries with the highest solar radiation levels in the world; this solar potential exceeds 6 billion GWh/year [12].

The economic potential for solar energy generation in Algeria has been assessed by the DLR and the CDER, mainly from satellite imaging and further processing. The derived economic potential data are gathered in the REs guide report by the MEM [11] and estimated at 169,440 TWh/year for thermal solar system.

Table 1
Main siting factors of concentrating solar power plant [9].

Siting factor	Requirement
Solar resource	Abundant > (1800 kWh/m^2/year) for economical operation.
Land use	20,234 m^2/MW of electricity production.
Land cover	Low diversity of biological species, limited agriculture value.
Site topography	Flat, slope up to 3%, 1% most economical.
Infrastructure	Proximity to transmission-line corridor, natural gas pipeline.
Water availability	Adequate supply, otherwise dry cooling.

4.2. Land use and land cover

Except for the solar resource assessment, concentrating solar power plants require a large land to locate it, approximately a land area of 20,234 m^2/MW of electricity (5 acres/MW). Plants with thermal storage and higher capacity factors will require proportionally more land per MW [10,14]. Siting studies have generally found that a land with an overall slope of less than 1% is the most economic to develop. Potential sites should have reasonable land costs, be generally level, and be close to transmission, water, and natural gas.

In addition to the large land requirement, the land for CSP sites should have low value for agricultural or residential use and have low biological habitat. In other words, the most suitable potential sites for CSP deployment are in the desert regions.

Almost 86% of the total surface of Algeria is desert (which represents 2,048,297 km^2); this indicates that the land availability will not become barrier in the future. But even then, not all desert lands are suitable, as the land topography, geology and soil quality also need to be considered. In general, lands with less than 3% slope are considered to be economical (3% slope may increase costs of up to 10%), and lands with less than 1% slope are considered to be of the most economical potential [10]. Other factors that require consideration include flood potential, seismic history, stability of soil, potential obstructions of the sun, and existence of dust or other debris that may degrade the effectiveness of mirror reflectors.

4.3. Water assessment

The primary requirement for water in a CSP power plant is for cooling the power cycle, replenishment of the working fluid HTF if a steam cycle is used, and secondary requirement is for solar field maintenance (basically for washing the mirrors) [15]. For current-use CSP systems, the water requirement ranges between 3 and 3.5 m^3/kWh, with 95% of the water usage attributed to the cooling tower and the remaining 5% of water consumption committed to mirror cleaning and to steam cycle working fluid [15,16]. High quality CSP sites with high levels of DNI are usually limited to arid and semi-arid deserts where water is not available easily or cheaply. As water-based cooling (cooling via evaporation) is technically considered the most efficient cooling technology available, the cost effectiveness of a CSP system with water cooling becomes dependent on the cost of bringing water to the site and more importantly on the cost of wasting a precious resource [9,15].

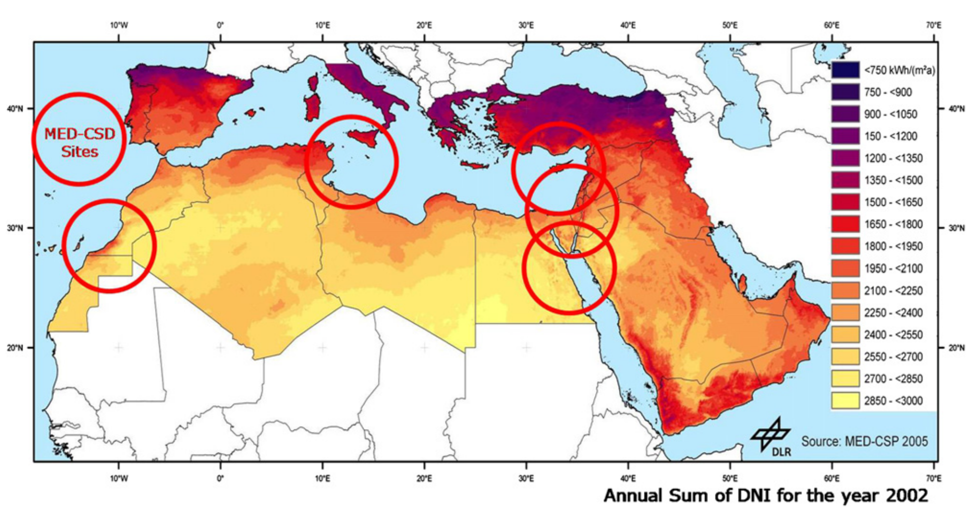

Fig. 4. Solar thermal electricity generating potentials in Algeria [13].

Table 2
Solar potential in Algeria.

Areas	Coastal area	High plains	Sahara	Total
Surface (%)	4	10	86	100
Area (km^2)	95,270	238,174	2,048,297	2,381,741
Mean daily sunshine duration (h)	7.26	8.22	9.59	
Average duration of sunshine (h/year)	2650	3000	3500	
Received average energy ($kWh/m^2/year$)	1700	1900	2650	
Solar daily energy density (kWh/m^2)	4.66	5.21	7.26	
Potential daily energy (TWh)	443.96	1240.89	14,870.63	16,555.48

The best scenario, then, is for the CSP site to be located close to an available and inexpensive water source (if no water resources are available or it is not economically feasible, dry cooling can also be considered with a cost and efficiency penalty). Dry cooling technology equipment currently costs about 3.3 times more than water cooling equipment and also increases parasitic power consumption (from fans) and lowers the overall efficiency of the steam cycle, resulting in an overall increase in electricity cost by 10% or more. This gives strong motivation to the improvement and cost reduction of dry cooling technology, which is indeed expected [15].

If the desert region considered has saline or otherwise unpotable water (as some deserts have, underground or in lakes) there is a good synergy in building a hybrid dual-purpose plant that uses solar energy to produce both electric power and fresh water by a water desalination process. Here, the desalting portion of the plant can use the low temperature rejected heat of the electric power plant and thus increase the system's overall economic viability significantly and also provide some of the water needed for the plant's operation.

Thus a careful assessment of water availability and cost assessments are important parts of the site section and system design process [9,10,15].

The traditional sources of water in Algeria are 19.3 billion cubic meters annually; availability of surface water is 12.4 billion cubic meters annually; 95% of these resources are in the north. Availability of groundwater is 6.9 billion cubic meters annually; 73% of these resources are in the south. For the non-traditional sources, the use of non-conventional water resources such as treated wastewater and desalinizated water is not yet common.

The salinity levels of surface water vary between 0.8 g/l and 1.5 g/l with the majority of resources having a salinity of less than 1 g/l. In the north, most groundwater is non-saline with less than 1 g/l salinity; in the south the salinity levels are variable and some sources have high salinity levels of up to 8 g/l [17].

4.4. *Transmission and power grid assessment*

Access to appropriate electric power transmission lines and natural gas pipeline is another crucial factor for site selection (natural gas pipeline networks are a crucial factor for solar–gas hybrid systems). As connecting the transmission line to the grid costs high, the proximity of CSP systems to a transmission power grid is an important factor in the overall calculation [18]. With fossil fuel, preferably natural gas, as supplement for the solar energy resource, the CSP has the capacity to provide firm power to the grid. However, the last issue is significant, but not determinant [14].

Algeria has an extensive alternating current (AC) network, not only covering the densely populated coastal areas, but also – due to the presence of its oil and gas industry – reaching far into the largely unpopulated center of the country. Owner of the grid is the state utility Sonelgaz, which is also responsible for operation, management and development of the grid, the grid is displayed in Fig. 5.

Recently the covering capacity for electricity installations network amounts to a rate of 98% in which more than 80% is in the north of the country. Algeria has over 225,309 km of power lines, serving almost the entire population with plans to increase the size of the network by 5% in coming years in order to reach isolated rural communities and hydrocarbon developments in the Sahara desert [19].

According to the company's definition, this number includes lines with voltage levels down to 60 kV. Transmission lines with 400 kV sum up to less than 1300 km length. Currently, Sonelgaz is putting strong efforts into upgrading these grid lines. Projects under construction include a 400 kV east–west transversal line, as well as a 400 kV line reaching into the deep south of the country. Reinforcements of cross-border connections with the neighboring countries Morocco, Tunisia and Libya, also on the basis of 400 kV technologies, are progressing. In September 2009, a new interconnection with Morocco, featuring a transfer capacity of 1000 MW, was inaugurated. Algeria's transnational interconnection projects with its Maghreb neighbors are part of a larger framework program, the so-called Mediterranean Ring Project (MED-RING), a 400 kV electricity circuit encompassing all countries of the Mediterranean basin.

Besides the terrestrial interconnections, Algeria also has plans for submarine electricity links with its European neighbors on the other shore of the Mediterranean. Discussion of interlink projects with Italy and Spain already started in the late 1990s—a time long before the ideas of Desertec or the Mediterranean solar plan appeared on the international agenda [19].

The Pipeline Transportation Activity provides for the delivery of hydrocarbons (crude oil, natural gas, LPG and condensate) through a pipelines network of almost 16,200 km (Fig. 6). Through this oil and gas pipelines system, 244.5 million toe (all products combined) were transported in 2007. The pipe transportation system counts 12 gas pipelines with a combined length of 7459 km, with a transportation capacity of 131 Bm^3/year, 39 Bm^3 of which are intended for exports. Since the commissioning of the 02 transcontinental gas pipelines, Enrico Matei (connecting Algeria to Italy via Tunisia) and Pedro Duran Farrel (linking Algeria to Spain via Morocco), new construction projects are being implemented, particularly in order to meet the European market's growing demand.

The pipeline transportation activity counts the following [20]:

- 79 pumping and compression stations equipped with more than 290 main machinery for a total power of over 02 million CV.
- A storage capacity of around 3.4 million m^3.
- A harbor loading capacity of around 210 MTA.
- A maintenance infrastructure organized around 03 maintenance main bases and 03 intervention regional bases.
- A gas dispatching national center (CNDG) in Hassi R'Mel.
- A liquid hydrocarbons dispatching center (CDHL) in Haoud El Hamra.

4.5. *Wind assessment*

Wind conditions at the site should also be considered in the siting assessments, since wind intensity determines the structural

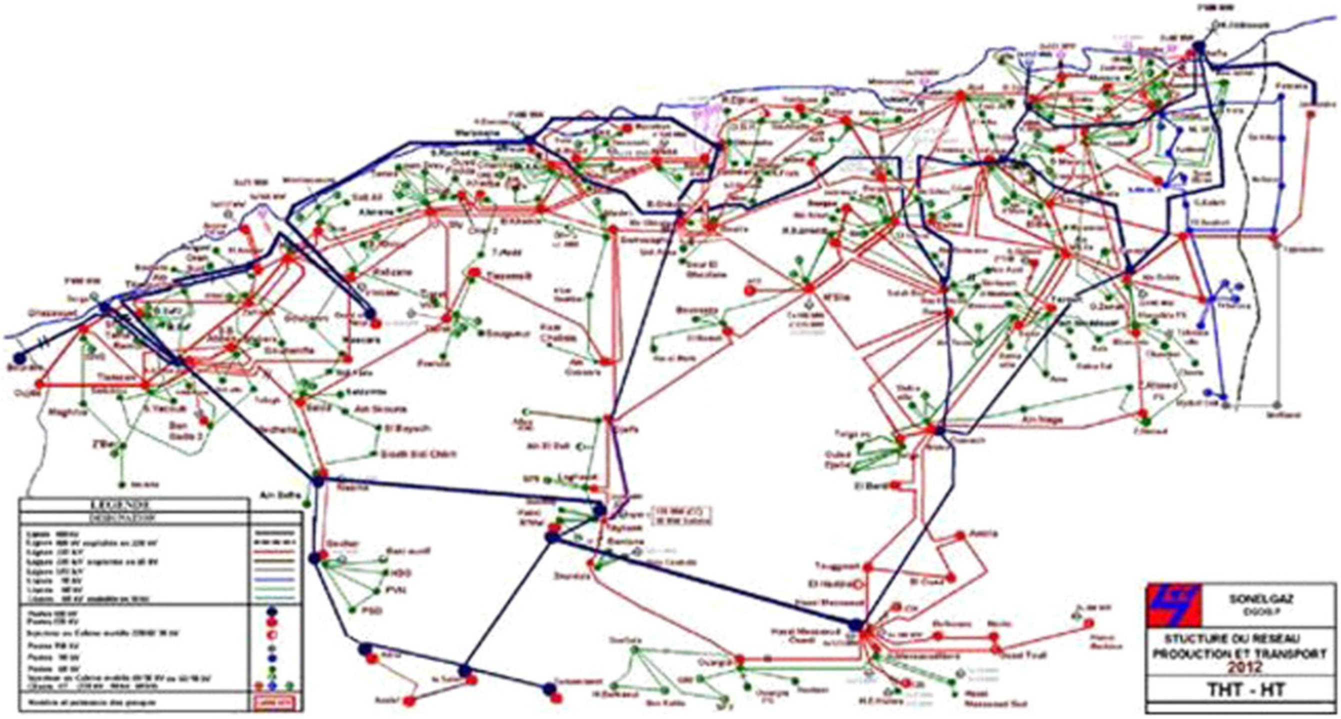

Fig. 5. Algerian electricity grid. Sonelgaz 2009 [12,19].

design of the collectors and the collector structures represent 40% of the solar field costs, the consideration of wind force is necessary to optimize this decision [14]. In the same reference, the SEGS plants are designed to operate at less than 35 mph winds and can operate in protected-mode (facedown position) in 80 mph winds. Wind turbines, rather than CSP systems should be considered in high wind areas.

The wind map of Fig. 7, established by CDER and MEM, shows that 50% of the country surface presents a considerable average speed of the wind, the map also shows that the south-western region experiences high wind speeds for a significant fraction of the year [21].

Except for solar energy resources, land use and land cover, water, transmission and power grid and wind assessments the other siting factors are not much different compared with those of the traditional steam power plant, such as economic assessment and waste products [18].

A feasibility study involving all these factors must be implemented before the location is determined for a CSP plant.

5. Parabolic trough power plant projects development in Algeria

Algeria sees ideal opportunities of combining Algeria's richest fossil energy source — natural gas — with Algeria's most abundant renewable energy source — the sun — by integrating concentrating solar power into natural gas combined cycles.

The Decree 04–92, published in the official Journal of Algeria in March 2004, promotes renewable energy systems, including CSP for hybrid solar–gas steam cycles, as well as integrated solar combined cycle systems (ISCCS). This decree sets a premium for the total ISCCS electricity production, depending on the solar share, from a 100% premium for a 5–20% solar share up to a 200% premium for a solar share over 25% [22].

According to the current power expansion planning of the MEM, the capacity targets for parabolic trough solar power implementation in Algeria are 500 MW of new ISCCS plants until 2020 [23]. As a first step 150 MW integrated solar combined cycle system (25 MW is devoted to solar), is currently in service.

5.1. The Hassi R'mel first integrated solar combined cycle (ISCC) plant

The 150 MW Hassi R′mel power plant in Algeria is the first integrated solar combined cycle power generating facility in the world [24], located at Algeria's largest natural gas field (Hassi R′mel) in the wilaya of Laghouat, 60 km from the wilaya of Ghardaia (Fig. 8), in an area close to gas pipelines and high voltage grid. This project was promoted by solar power plant one (SPP1), an Abener and NEAL joint venture formed for this purpose, which operates and exploits the plant for a period of 25 years. The plant construction started on the 7th of November 2007 and finished in November 2010. SONATRACH will buy all of the power produced, which is expected to reach 1250 GWh/year [25].

The plant consists of two 40 MW gas turbines, one 80 MW steam turbine, and two parabolic trough solar fields with a generating capacity of 25 MW. The solar fields comprise 224 parabolic collectors in 56 loops in an area measuring 180,000 m^2 (equivalent to 17 full-size soccer fields), with an inlet heat transfer fluid temperature of 290 °C and an outlet temperature of 390 °C. The Hassi R′mel plant will use the heat generated in the same steam turbine that makes use of the waste heat from the gas turbine for electricity generation; this configuration is double effective, since it not only minimizes the investment cost but also reduces the CO_2 emissions associated with the conventional plant. 20% of the project cost (63 million Dollars) is financed by shareholders, and the rest 80% (252 million Dollars) is financed by local banks (BEA—54.72%, CPA—20.03% and BNA—25.25%) on a non-recourse project financing basis. Project assets and cash flow are the only security to lenders, while the project cash flow is used to service the debt and distribute dividends. Finally, a 15-year of

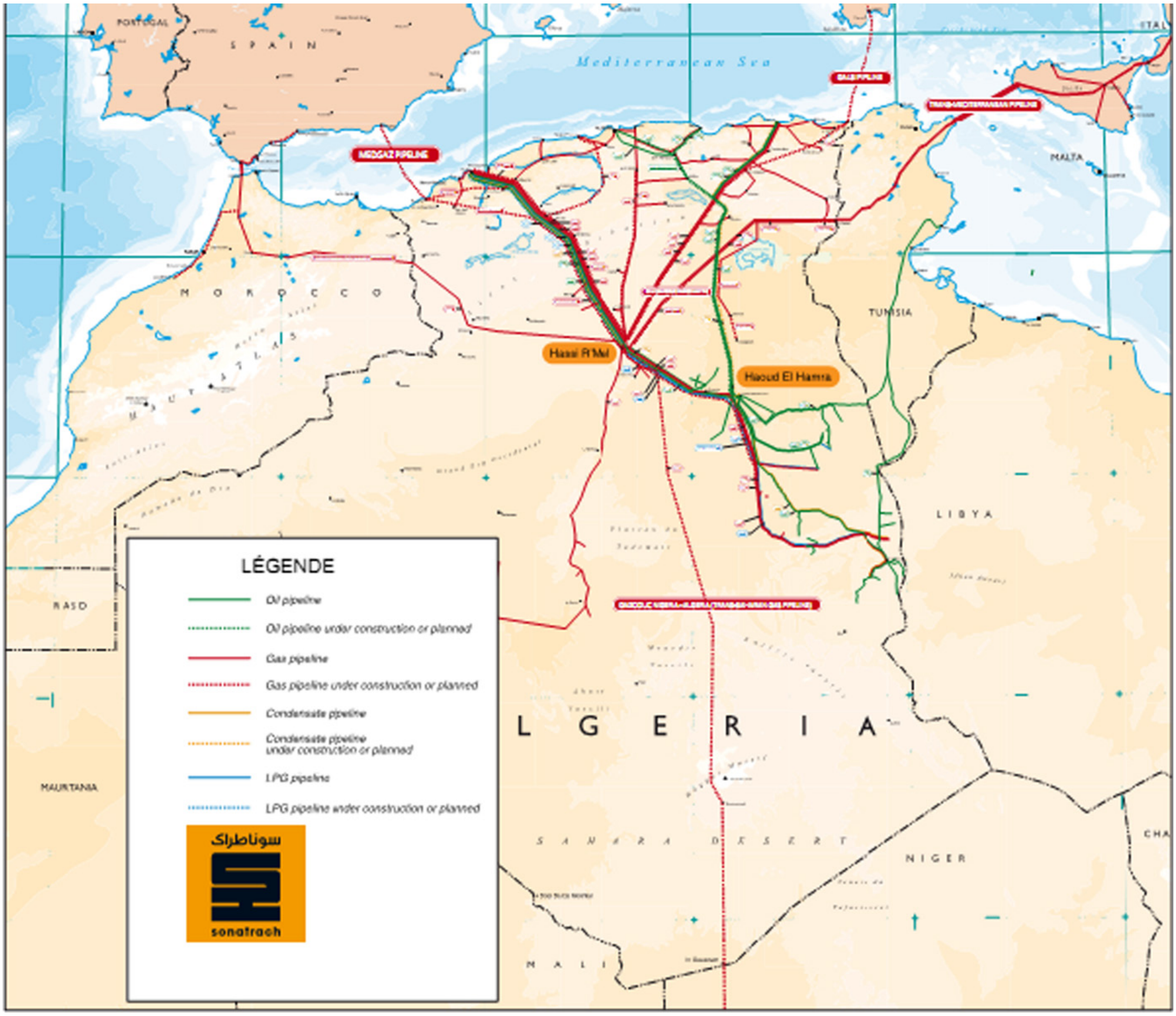

Fig. 6. Pipeline transportation network in Algeria [20,21].

repayment "soft loan" of 3.75% interest rate has been received to reduce the impact of financing charges on tariffs [25].

Main characteristics of the project [3]:

5.1.1. Location

Hassi R′mel, wilaya of Laghouat, 60 km from the wilaya of Ghardaia. The site was chosen on the basis of the following criteria:

- Availability of an exceptional solar resource (DNI).
- Availability of natural gas.
- Easy access to the power grid.
- Availability of water.
- Site flatness.

5.1.2. Technical description of the project:

- Technology: Integrated Solar Combined Cycle System ISCCS.
- Construction and management of the power plant on the basis of builder operator owner (B.O.O.).
- Capacity: 25 MW parabolic trough solar power plant, 150 MW in total.
- Area: 152 ha.

5.1.3. Uses of the power plant

- Water: Hassi R′mel region recycles water in a treatment station that affords around 2500–3000 m^3 a day.
- Gas supply: sufficient gas supply for the project from the largest gas field in Algeria.
- Power: access to the national electrical power network and presence of a power plant.

5.1.4. Financial data

Option chosen for the financing of the project: local investment cost of the project: € 315.8 million.

5.1.5. Selected bidder

The chosen bidder is the Spanish company ABENER.

5.1.6. Structure of the company

A company was created to manage the operation and maintenance of a joint venture between: ABNER 66%, NEAL 20% and a

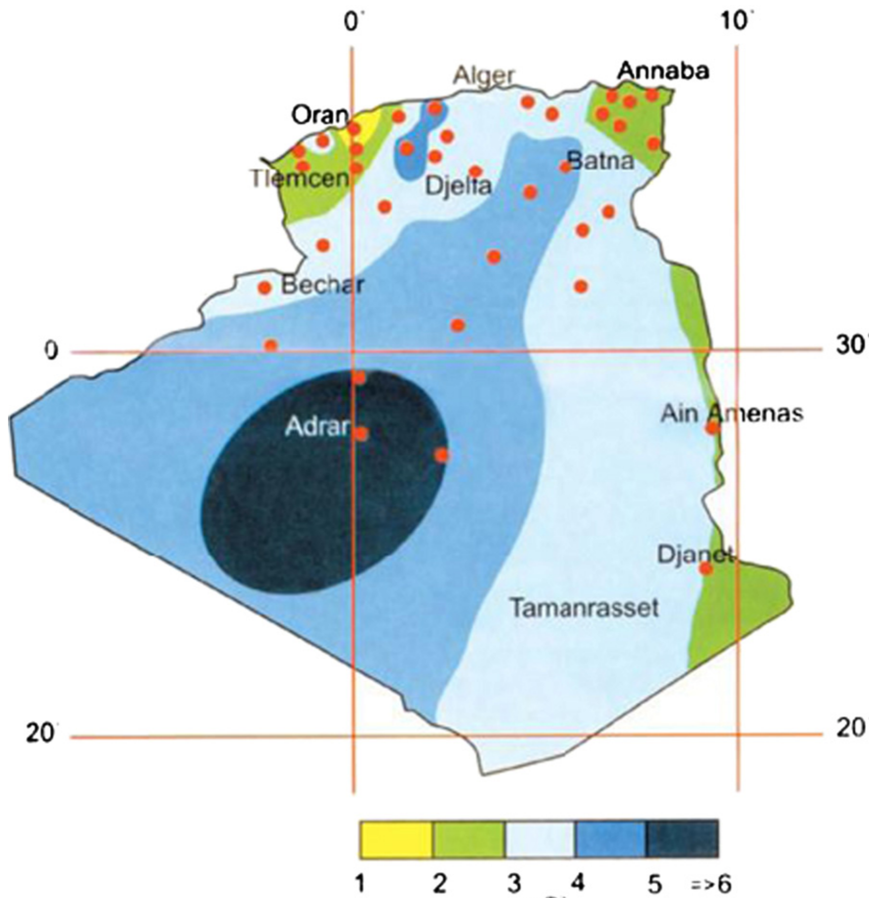

Fig. 7. Wind chart of Algeria.

Fig. 8. Hassi R'mel zone.

Table 3
Three new solar integrated projects under various stages of consideration [3,19].

Solar–gas hybrid power plant	Location	Installed CSP capacity (MW)	COD
SPP II: Solar power plant	Meghaïer	70	2014
SPP III: Solar power plant two	Naâma	70	2016
SPP IV: Solar power plant three	Hassi R'mel	70	2018

bank consortium (BEA, CPA and BNA) the leader of 14% of which is BEA.

5.1.7. Signing of the contact package of the project

All the contracts relating to this project were signed on 12-16-2006 in presence of the MEM [3].

5.2. Future parabolic trough power plant projects in Algeria

Three further hybrid power plant units are to be completed by 2018, with 70 MW parabolic trough solar power plants capacity for each one of them; each one will be scale-ups of Hassi R'mel, and are part of the government's plan to develop electricity production and exports from renewable energies in Algeria.

Table 3 lists the new PTSTPP proposed generation projects in the Algerian investment plan under MENA CSP scale-up programme, with a scheduled accumulated CSP capacity of 210 MW.

Two options are being considered for the first project, which will be located in Meghaïer, in the southeast part of Algeria. Both would include a 270–280 ha solar island using parabolic trough:

Option 1: power production only, total capacity 400 MW, of which 70 MW was generated from PTSTPP.

Option 2: integrated desalination/power production, total capacity 480 MW, of which 80 MW PTSTPP (the plant would treat local brackish water) [3].

6. Conclusion

Against the background of an increasing energy demand and growing environmental problems in Algeria due to the use of fossil fuels, parabolic trough solar thermal power plants (PTSTPP) technologies offer interesting opportunities for Algeria.

Algeria has favorable climatic conditions for the construction of parabolic trough solar thermal power plants, with 1,787,000 km^2 the largest long term land potential for the concentrating solar power (CSP) in the Mediterranean basin. In addition, the value of solar radiation falls between 4.66 kWh/m^2 and 7.26 kWh/m^2; this corresponds to 1700 kWh/m^2/year in the north and 2650 kWh/m^2/year in the south, and the insolation time over the quasi-totality of the national territory exceeds 3000 h annually and may reach 3500 h in high plains and Sahara, with this huge quantity of sunshine per year, Algeria is one of the countries with the highest solar radiation levels in the world, with Algeria's Saharan regions characterized by mostly flat and unproductive desert lands and sufficient water resources; Algeria also has the land and grid infrastructure needed for successful PTSTPP deployment.

Algeria sees ideal opportunities of combining Algeria's natural gas with solar energy by integrating concentrating solar power into natural gas combined cycles, such as the 150 MW Hassi R'Mel power plant which is the first integrated solar combined cycle power system generating facility in the world, in addition to three further hybrid power plant units to be completed by 2018, with 70 MW CSP capacity for each one of them.

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